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Reinforcing Impact Factor of a Vendor as an Indirect Measure of Quality in Vendor Selection Problem: A Study Through Simulation

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Abstract: A Vendor Selection Problem generally consists of four steps: problem definition, formulation of criteria, qualification of suitable vendors and final selection *[**De Boer et al. (2001)**]*. Impact factor has been introduced only recently [*(**Kaur and Chakraborty (2007**)*] as an indirect measure of quality and defined as *the ratio of number of offers per year that a certain vendor gets divided by the number of different types of goods produced per year by him/her.* Higher impact factor carries greater weightage. A fuzzy-statistical comparative case study was presented in the introductory paper where it was found that the vendor who got the highest allocation was the one who had the highest impact factor. Accordingly it was argued that in situations where figures for % defects (which is how quality is generally expressed) are not available or the customer does not consider them as reliable as claimed by the vendors or even if they are available and reliable, the customer wants a quality assurance over and above what is claimed by the vendor, it might be worthwhile to use impact factor as an indirect measure of quality. However, as it was only one case study, we decided to conduct several such studies through Monte Carlo simulation to substantiate matters. This is precisely what is done in the present paper.

Key words: Vendor Selection Problem, Fuzzy numbers, Z Score, Impact Factor.

INTRODUCTION

There are two basic decisions that need to be made in the Vendor Selection Process. Firstly the firm must decide which vendors it should contract and secondly it must determine the appropriate order quantity for each vendor selected. We refer to these decisions as the Vendor selection problem [*Weber and Current (1993)*]. The problem is complicated by the fact that vendor selection is often an inherently multicriteria one. Some of the past literatures classified the criteria as quantitative and qualitative or tangible and intangible. In general, most of the researchers have identified cost, quality and service as their main criteria. [*Dickson (1966), Weber (1991) and Boer (2001)]* reviewed, classified various articles related to vendor selection problem according to criteria or methodology. Other researchers have used different methods for vendor selection like Linear Weighting Methods [*Timmerman (1986), Wind and Robinson (1968), Cooper (1977)*], Mathematical Programming Models [*Chaudhary, Frost and Zydiak (1991), Buffa and Jackson (1983), Ghodspouri and Brien (2001*)], Statistical/Probabilistic Methods [*Verma and Pullman (1998), Vonderembse and Tracey (1999) and Talluri and Narasimhan (2003)*] and Total Cost of Ownership Models [*Degraeve, Labro and Roodhooft (1999,2000)*]. In all the above methodologies adopted in general we observe that there is more subjectivity of the decision maker in identification of weights for various criteria. Sometimes input information is not known precisely. These are some of the shortcomings that need to be dealt with.

Fuzzy set theory (FST) has proven advantages within vague, imprecise and uncertain contexts and it resembles human reasoning in its use of approximate information and uncertainty to generate decisions. At the time of making decisions, the value of many criteria and constraints are expressed in vague terms such as "very high in quality" or "low in price". Deterministic models cannot easily take this vagueness into account. In these cases, the theory of fuzzy sets is one of the best tools for handling uncertainty. FST's are employed due to the presence of vagueness and imprecision of information in the vendor selection problem. From review we notice that several techniques equipped with fuzzy logic has proved to be useful. To deal with uncertainty and non-linearity of the behavior of the experts involved in this decision-making process a fuzzy logic in vendor rating based on fuzzy logic system and neural network was proposed by [*Albino, Garavelli and Gorgoglione (1998]) and [Nassimbeni and Battain (2003)].* A fuzzy multiobjective integer programming and

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fuzzy mixed integer goal programming [(*Kumar, Vrat and Shankar (2004,2006)*] was used to facilitate the vendor selection and quota allocation under different degrees of information vagueness in the decision parameters of a supply chain modeling. [*Chou, Shen and Chang (2006)*] proposed a fuzzy factor rating system to evaluate the potential vendors based on the type of components required by the customers. [*Harun and Taskin (2007*)] proposed a fuzzy supplier selection algorithm to rank the technically efficient vendors according to both predetermined performance criteria and product related performance criteria.

We conclude by saying that the use of fuzzy logic enables the decision makers to eliminate or at least contain the problem stemming from the subjective and ambiguous nature of their information.

The organization of the rest of our paper is as follows: Section two gives the methodology and the formulation of a linear programming model followed by a fuzzy model for VSP. Impact factor is also defined and explained here. In section three we attempt to reinforce the concept of impact factor as an indirect measure of vendor's quality through three samples studies each obtained through simulation. In section four the main finding of our results are explained. In section five we summarize our results.

MATERIALS AND METHODS

2.1 Z-Score:

Suppose we are interested in determining which Vendor is more consistent in his abilities and which one has the greater variability within him. Would a comparison of the standard deviations of the two sets of raw scores give us the answer? The reply to most of these questions is in the negative. We are extremely limited in making direct comparisons in terms of raw scores for the reason that raw score scales are arbitrary and unique. We need a common scale before comparisons such as we have called for can be made. Standard scores furnish one such common scale.

A standard score scale has a mean of zero and a standard deviation of 1.0.

Standard score [(***Garret (1966))***] corresponding to a raw score X and to a deviation from mean is defined as follows:

$$z = \frac{X - M}{\sigma} \tag{1}$$

where deviation from mean M is X-M and σ is the standard deviation.

One shortcoming of the standard score is that half the scores will be negative in sign, which makes computation awkward. We overcome this shortcoming by adding a constant to all the scores to make them all positive.

We are also introducing a new term called the **impact factor** of the vendor defined as *the ratio of the number of offers the vendor gets (from different customers or from the same customers on different occasions) divided by the number of types of goods produced by the vendor in a year.* Higher impact factor will carry greater weightage. We supply the necessary mathematics and interpretation of this new concept below.

Let x be the no. of offers / year obtained by a particular vendor.
Let y be the no. of different types of goods produced / year by this vendor.

Then I.F = Impact Factor of the vendor = $\frac{x}{y}$

Clearly y $\neq$ 0 as the vendor must produce goods of at least one kind/year in order to qualify to be a potential vendor (or else he is not considered in the analysis!).

Interpreting Quality as Judged by I.F:

To interpret quality as judged by the I.F. we consider the following four cases:

Case 1: If x = 0 i.e. $\frac{y}{x} = \infty$ .F.=0 we define Quality =1 (as if % defective=1 which is worst)

Case 2: If $0 < \frac{y}{x} < 1$ define Quality = $\frac{1}{I.F}$ = $\frac{y}{x}$

Case 3: If $1 < \frac{y}{x} < \infty$ define Quality = 1 - $\frac{x}{y}$ = 1- ($\frac{y}{x}$

Observe that in this case as $\frac{y}{x}$ tends to infinity, Quality tends to 1. On the other hand, as $\frac{y}{x}$ tends to 1 , quality tends to zero. However it is understood here that quality will never be zero as no vendor can be perfect if judged through I.F. The case of $\frac{y}{x}$ being 1 which is quite possible is being separately dealt with in case 4.

Case 4: If $\frac{y}{x}$ =1, we say that quality is the minimum expected for the vendor for in this case the vendor is getting as many offers as the number of different types of goods (either one offer for each type or more than one offer in some to compensate for no offer in others). In probabilistic terms since quality ε [0,1], we may define this minimum expected quality as *the expectation of the minimum or first order statistic for a random sample from U[0,1] distribution*. For practical purpose we shall take a large number of samples each of size equal to the number of vendors and find the minimum sample observation (value of first order statistic) for each sample. Next we find their mean, which gives an estimate of the minimum expected quality of the vendor for whom $\frac{y}{x}$ =1.

Evidently the final value of quality says Q will be in (0, 1]. Hence we can safely apply the mathematics that we normally do for quality although the interpretation of quality as judged from the I.F. is different.

We hereby claim a novelty in our approach to vendor selection problem, through the usage of Z-Scores as a standardized score in that the further analysis for optimal allocation will now be based on Z-Scores rather than the original data. However Z-Score has been used in AHP involving only pair-wise comparison of data. Ours is a more general setup. Secondly, the use of impact factor as an indirect measure of quality is a totally new endeavour. This will be reinforced through strong simulation results.

2.2 Model Formulation:

2.2.1 The Linear Model for Vendor Selection [Ghodsypour and Brien (1998)]:

Notations:

R_i final ratings of i^{th} Vendor (Here total of Z -Scores for i^{th} Vendor)
X_i Order quantity for i^{th} Vendor
V_i Capacity of i^{th} Vendor
D Demand for the period
q_i Defect percent of i^{th} Vendor
Q Buyer's maximum acceptable defect rate

The Objective function
The objective here is to maximize the total value of purchasing (TVP).

$$\text{Max (TVP)} = \sum_{i=1}^{n} R_i X_i \tag{2}$$

Subject to:

Capacity Constraints:

As vendor i can provide up to V_i units of the product and its order quantity (X_i) should be equal or less than its capacity, these constraints are:

$X_i \leq V_i$, i=1, 2 … n. (3)

On the other hand, aggregate Vendors' capacity should be equal or greater than demand, therefore,

$$\sum_{i=1}^{n} V_i \geq D \tag{4}$$

Demand Constraint:

As the sum of the assigned order quantities to n vendors should meet the buyer's demand, it can be stated that

$$\sum_{i=1}^{n} X_i = D \tag{5}$$

Quality Constraint:

Since Q is the buyer's maximum acceptable defect rate and q_i is the defect rate of the i^{th} vendor, the quality constraint can be shown as

$$\sum_{i=1}^{n} X_i q_i \leq QD \tag{6}$$

Crisp Model:

The final integrated linear programming model (crisp) can be stated as

$$\text{Max (TVP)} = \sum_{i=1}^{n} R_i X_i \tag{7}$$

Subject to:

$\sum_{i=1}^{n} X_i = D$ (Demand constraint),

$\sum_{i=1}^{n} X_i q_i \leq QD$ (Aggregate quality constraint), (8)

$X_i \leq V_i$ i = 1,2, … ,n (Vendor's capacity constraints),

$X_i \geq 0$, i = 1,2, … , n (Nonnegativity constraint)

2.2.2 Fuzzy Sets and Fuzzy Numbers [Klir and Yuan (2002)]:

Fuzzy Set:

The characteristic function of a crisp set assigns a value of either 1 or 0 to each individual in the universal set, thereby discriminating between members and nonmembers of the crisp set under consideration. This function can be generalized such that the values assigned to the elements of the universal set fall within a specified range and indicate the membership grade of these elements in the set in question. Larger values denote higher degrees of set membership. Such a function is called a ***membership function***, and the set defined by it a ***fuzzy set*** .

The most commonly used range of values of membership functions is the unit interval [0,1]. In this case, each membership function maps elements of a given universal set X, which is always a crisp set, into real numbers in [0,1].

The membership function of a fuzzy set A is denoted by μ_A that is,

$$\mu_A : X \rightarrow [0,1]$$

The ***support*** of a fuzzy set A within a universal set X is the crisp set that contains all the elements of X that have nonzero membership grades in A.

The ***height***, h(A), of a fuzzy set A is the largest membership grade obtained by any element in that set. Formally,

$$h(A) = \sup_{x \in X} A(x)$$

A fuzzy set A is called ***normal*** when h(A)=1; it is called ***subnormal*** when h(A)<1.

Fuzzy Number:

To define a fuzzy number, a fuzzy set A on R must possess at least the following three properties:

1. A must be a normal fuzzy set;
2. ${}^{\alpha}A$ must be a closed interval for every α ε (0,1];
3. The support of A, ${}^{0+}A$, must be bounded.

Triangular Fuzzy Number (TFN):

A fuzzy number $\tilde{A}$ of the universe of discourse U may be characterized by a triangular distribution function parameterized by a triplet (a, b, c) shown in Fig.5. The membership function of the fuzzy number $\tilde{A}$ s defined as

$$f_{\tilde{A}}(u) = \begin{cases} 0, & u < a \\ \dfrac{u-a}{b-a}, & a \leq u \leq b, \\ \dfrac{c-u}{c-b}, & b \leq u \leq c, \\ 0, & u > c. \end{cases}$$

The TFN is easy to use and interpret. For example in VSP a very significant weight for specific criteria can be measured by a TFN and denoted by (43000,44181,45000) (**Table 4**). Additionally the TFN can also be used to represent the quantitative terms. For example, “approximately equal to 790” can be represented by (787,790,792);”approximately between 765 and 769” can be represented by (765,767,769).

Let Ã and $\tilde{B}$ be two fuzzy numbers (TFN) parameterized by the triplet say (a_1,a_2, a_3) and (b_1,b_2,b_3), respectively.

Then the operations of fuzzy numbers are expressed as:

Ã (+) $\tilde{B}$ = (a_1, a_2, a_3) (+) (b_1,b_2,b_3) = $(a_1+b_1,a_2+b_2,a_3+b_3)$,

Ã (-) $\tilde{B}$ = (a_1 ,a_2,a_3) (-) (b_1,b_2,b_3) = $(a_1-b_3,a_2-b_2,a_3-b_1)$,

Ã (*) $\tilde{B}$ = (a_1, a_2,a_3) (x) (b_1,b_2,b_3) = (a_1b_1,a_2b_2,a_3b_3),

$\tilde{A}\ (\div)\ \tilde{B} = (a_1, a_2, a_3)\ (\div)\ (b_1, b_2, b_3) = (a_1/b_3, a_2/b_2, a_3/b_1)$.

α-cut:

Given a fuzzy set A defined on X and any number α ε [0,1], the α-cut and the strong a-cut, ${}^{\alpha}A$, are the crisp sets

$$ {}^{\alpha}A = \{ x \,/\, A(x) \geq \alpha \} $$
$$ {}^{\alpha+}A = \{ x \,/\, A(x) > \alpha \} $$

That is, the α-cut (or the strong α-cut) of a fuzzy set A is the crisp set ${}^{\alpha}A$ (or the crisp set ${}^{\alpha+}A$) that contains all the elements of the universal set X whose membership grades in A are greater than or equal to (or only greater than) the specified value of α.

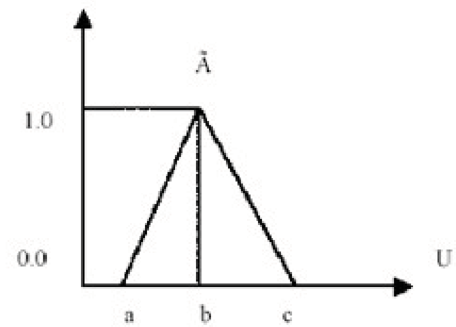

Fig. 1: Triangular fuzzy number.

Defuzzification:

The defuzzification of a triangular fuzzy number (a, b, c) is equal to

$$ e = \frac{a + 2*b + c}{4} \tag{9} $$

2.2.3 Fuzzy Model for Vendor Selection:

Fuzzy concepts are necessitated in a vendor selection problem when a decision maker has some vague or unreliable information about the data at hand. In that case the coefficients in the problem can be defined by fuzzy set theory.

In the fuzzy model the value of objective function (i.e. total of Z-Scores) are expressed in terms of triangular fuzzy numbers. So the model becomes

$$ \text{Max (TVP)} = \sum_{i=1}^{n} \tilde{R}_i X_i \tag{10} $$

Subject to:

$$ \sum_{i=1}^{n} X_i = D \quad \text{(Demand constraint),} $$

$$ \sum_{i=1}^{n} X_i q_i \leq QD \quad \text{(Aggregate quality constraint),} $$

$X_i \leq V_i$ i = 1,2, … ,n (Vendor's capacity constraints),

$X_i \geq 0$, i = 1,2, … , n (Nonnegativity constraint)

Numerical Example:

Assume that the management of a just in time (JIT) manufacturer decides to choose their best Vendors and assign their optimum order quantities to maximize the total value of purchasing. The main criteria for vendor selection are Cost, Quality and Service. Ten vendors are included in the evaluation process and three samples of data randomly generated using Monte Carlo simulation [***Kennedy and Gentle (1980)***] are shown in **Tables 1-3**. The fuzzy data represented by triangular fuzzy numbers are shown in **Tables 4-6.** Also the three programs are shown in ***Appendix*** through which data have been generated from specific probability distributions as detailed next. Suppose the buyer wishes to find the best vendor and their optimum order quantities, if demand is 1000 units and maximum acceptable defect rate is different for the three samples (say 0.15, 0.1 and 0.6).

Price: Random integer from 30,000 to 50,000
Quality in terms of impact factor: x is a random integer from 0 to 50
y is a random integer from 1 to 5.
Capacity: Random integer from 500 to 1000.
Time delay: Exponential variates with mean 1.

Table 1: Sample one

Vendor	Price	x	Y	Quality (in terms of IF)	Capacity	Time Delay
1	44111	35	4	.1143	853	1.22
2	40669	27	3	.1111	767	.76
3	41590	29	3	.10345	790	.87
4	35791	14	2	.14286	645	.34
5	36039	15	2	.1333	651	.36
6	45495	39	4	.10256	888	1.49
7	30280	0	1	1	507	.014
8	45215	38	4	.10526	881	1.43
9	46290	41	5	.12195	908	1.68
10	44181	36	4	.1111	855	1.23

Table 2: Sample two

Vendor	Price	x	Y	Quality (in terms of IF)	Capacity	Time Delay
1	33822	46	3	.0652	822	1.417335
2	31221	0	2	1	522	.2496075
3	30869	38	4	.1053	528	4.258759
4	45141	43	1	.0233	904	1.091501
5	36429	10	5	.2	944	.5050457
6	39011	8	3	.375	799	1.800406
7	45669	24	5	.2083	907	1.622946
8	31238	25	3	.12	784	.6703613
9	31655	10	4	.4	893	.4307552
10	37770	33	3	.09091	813	2.924567

Table 3: Sample three

Vendor	Price	x	Y	Quality (in terms of IF)	Capacity	Time Delay
1	33273	6	2	.3333	932	.01222
2	45058	3	3	.09123*	890	1.696983
3	32798	27	2	.0741	842	1.279723
4	49043	36	3	.0833	722	.6849341
5	35660	5	1	.2	715	.2214334
6	48507	9	5	.5556	805	.7717941
7	35619	18	4	.2222	926	.4547798
8	46074	1	1	.0892**	610	1.535559
9	33088	3	4	.25***	765	.709870
10	35659	38	4	.1053	641	.4016084

*Quality obtained using case 4 of impact factor.
**Quality obtained using case 4 of impact factor.
***Quality obtained using case 3 of impact factor.

Table 4: Fuzzy data for sample One

	Price	Quality	Capacity	Time Delay
Vendor 1	(43000,44111,45000)	(.1,.1143,.12)	(850,853,855)	(1.2,1.22,1.3)
Vendor 2	(39000,40669,41,000)	(.1,.1111,.12)	(765,767,769)	(.75,.76,.79)
Vendor 3	(40000,41590,42000)	(.09,.10345,.11)	(787,790,792)	(.85,.87,.9)
Vendor 4	(34000,35791,36000)	(.13,.14286,.13)	(643,645,647)	(.31,.34,.37)
Vendor 5	(35000,36039,37000)	(.12,.1333,.14)	(649,651,653)	(.34,.36,.38)
Vendor 6	(44000,45495,31000)	(.09,.10256,.11)	(885,888,890)	(1.45,1.49,1.51)
Vendor 7	(29000,30280,31000)	(.9,1,1.1)	(505,507,510)	(.012,.014,.016)
Vendor 8	(44000,45215,46000)	(.09,.10526,.11)	(879,881,885)	(1.4,1.43,1.5)
Vendor 9	(45000,46290,47000)	(.11,.12195,.13)	(906,908,911)	(1.65,1.68,1.71)
Vendor 10	(43000,44181,45000)	(.1,.1111,.12)	(853,855,857)	(1.21,1.23,1.27)

Table 5: Fuzzy data for sample Two

	Price	Quality	Capacity	Time Delay
Vendor 1	(32000,33822,34000)	(.05,.0652,.07)	(810,822,830)	(1.3,1.4173,1.5)
Vendor 2	(30000,31221,32000)	(.5,1,1.5)	(510,522,530)	(.1,.2496,.3)
Vendor 3	(29000,30869,31000)	(.09,.1053,.11)	(510,528,530)	(.5,1.2588,2)
Vendor 4	(44000,45141,46000)	(.01,.0233,.03)	(800,904,1000)	(.4,.505,.6)
Vendor 5	(35000,36429,37000)	(.1,.2,.3)	(800,944,1000)	(.5,1.8004,2)
Vendor 6	(38000,39011,40000)	(.2,.375,.4)	(600,799,800)	(.5,1.6229,2)
Vendor 7	(44000,45669,46000)	(.1,.2083,.3)	(800,907,1000)	(.5,1.6229,2)
Vendor 8	(30000,31238,32000)	(.01,.12,.13)	(600,784,800)	(.5,.6704,.7)
Vendor 9	(30000,31655,32000)	(.3,.4,.5)	(700,893,900)	(.3,.4308,.5)
Vendor 10	(36000,37770,38000)	(.08,.09091,.1)	(700,813,900)	(1,2.9246,3)

Table 6: Fuzzy data for sample Three

	Price	Quality	Capacity	Time Delay
Vendor 1	(31000,33273,36000)	(.31,.3333,.35)	(930,932,935)	(.011,.01222,.012)
Vendor 2	(42000,45058,47000)	(.07,.09123,.1)	(880,890,900)	(1.4,1.6969,1.8)
Vendor 3	(30000,32798,35000)	(.05,.0741,.09)	(840,842,845)	(1,1.2797,1.4)
Vendor 4	(47000,49043,50000)	(.06,.0833,.09)	(721,722,724)	(.65,.6849,.7)
Vendor 5	(33000,35660,37000)	(.05,.2,.4)	(713,715,718)	(.2,.2214,.24)
Vendor 6	(45000,48507,50000)	(.1,.5556,.7)	(803,805,808)	(.75,.7718,.79)
Vendor 7	(33000,35619,38000)	(.4,.2222,.3)	(925,926,927)	(.43,.4548,.47)
Vendor 8	(44000,46074,48000)	(.1,.0892,.1)	(609,610,613)	(1.3,1.5356,1.7)
Vendor 9	(30000,33089,35000)	(.06,.25,.45)	(764,765,768)	(.5,.7099,.9)
Vendor 10	(33000,35659,36000)	(.08,.1053,.12)	(639,641,643)	(.2,.4016,.5)

In order to solve these problems, two types of calculations were carried out: Z-Scores and Linear Programming optimization for both fuzzy and crisp case. The steps of the algorithm are defined as follows:

Step 1: The data, which has been generated randomly for ten vendors for evaluation, follows uniform distribution. The impact factor is calculated from data generated by using the four case studies [***Kaur and Chakraborty, (2007)***].

Step 2: We calculate the Z-Scores for each vendor using data from **Tables 4-9** for both fuzzy and crisp case. Tables show the Z-Scores for the ten vendors. The Z-Scores are calculated using equation (1). As far as fuzzy Z-Scores are concerned we use the same formula as for crisp case, except that we defuzzify it using equation (9).

SAMPLE 1 Case 1: CRISP

Table 7: Z-Scores of criteria and its total

VENDOR	Z-Score of Price	Z-Score of Quality (in terms of Impact Factor)	Z-Score of Capacity	Z-Score of Time Delay	Total of Z-Scores
1	2.8254	.0283	2.8235	2.3269	8.0041
2	2.1409	.02082	2.1404	1.4644	5.7665
3	2.3241	.00293	2.3231	1.6706	6.3207
4	1.1708	.095076	1.1714	.6768	3.1141
5	1.2202	.07272	1.2191	.71431	3.2263
6	3.1006	.00085	3.1015	2.8332	9.0362
7	.0749	2.09914	.07529	.06552	2.3149
8	3.045	.007164	3.0459	2.7207	8.8187
9	3.2587	.046187	3.2604	3.1895	9.7548
10	2.8393	.020818	2.8389	2.3457	8.0452

Value of the objective function = 9677.909 Allocation of order to the vendors is as follows:

$\mathbf{X_1=0, X_2=0, X_3=0, X_4=0, X_5=0, X_6=107, X_7=0, X_8=0, X_9=893, X_{10}=0}$

Comment: The highest allocation goes to the ninth vendor whose quality in terms of impact factor was .12195, which is good enough. This vendor also had the highest Z-Score, which is contributed by high price and high capacity. High capacity is a qualification. The logic supporting high price is that he must be supplying products of good quality with reasonably high price. Of course he also had a maximum time delay but this is outweighed by the other qualifications.

Case 2 :FUZZY

Table 8: Z-Scores of criteria and its total

VENDOR	Z-Score of Price	Z-Score of Quality (in terms of Impact Factor)	Z-Score of Capacity	Z-Score of Time Delay	Total of Z-Scores
1	2.7362	.0033	2.6652	1.8737	7.2784
2	1.9898	.0008	1.8658	1.3535	5.2099
3	2.1804	.5923	1.9267	1.5439	6.2433
4	1.0187	.0637	.9711	.5659	2.6194
5	1.1647	2.4428	.987	.6172	5.2117
6	2.9575	.5916	2.7579	2.2724	8.5794
7	.0056	1.5888	.034	.0845	1.7129
8	2.939	.5938	2.7393	2.2349	8.507
9	3.1397	.022	3.3825	3.1578	9.702
10	2.8683	.0008	2.6705	2.2553	7.7949

Value of the objective function =22198.59

Allocation of order to the vendors is as follows:

$X_1=0, X_2=0, X_3=0, X_4=0, X_5=0, X_6=0, X_7=0, X_8=107, X_9=893, X_{10}=0$

Comment: In fuzzy case also the maximum allocation went to the ninth vendor whose allocation order is same as in crisp case i.e.893. However the value of the objective function is more which is expected for the fuzzy case where because of membership function the range of the objective function is much wider.

FOR SAMPLE 2
CASE 1: CRISP

Table 9: Z-Scores of criteria and its total

VENDOR	Z-Score of Price	Z-Score of Quality (in terms of Impact Factor)	Z-Score of Capacity	Z-Score of Time Delay	Total of Z-Scores
1	.7384	.1945	2.2133	1.1356	4.2818
2	.2504	3.6012	.1081	.1569	4.1166
3	.1843	.3406	.1502	3.5092	4.1843
4	2.8620	.0418	2.7888	.8609	6.5535
5	1.2275	.6857	3.0695	.3706	5.3533
6	1.7119	1.3235	2.0519	1.4537	6.541
7	2.9611	.7160	2.8098	1.3053	7.7922
8	.2536	.3942	1.9467	.5088	3.1033
9	.3318	1.4146	2.7116	.3085	4.7665
10	1.4791	.2882	2.1502	2.3938	6.3113

Value of the objective function =7677.001

Allocation of order to the vendors is as follows:

$X_1=0, X_2=0, X_3=0, X_4=93, X_5=0, X_6=0, X_7=907, X_8=0, X_9=0, X_{10}=0$

Comment: The highest allocation goes to the seventh vendor, whose quality in terms of IF is .2083, which is fair enough. This vendor also had the highest Z-Score, which is contributed, by high cost but not the highest capacity (second highest) or highest time delay (fourth highest). The interpretation for high cost and high capacity is same as before.

CASE 2: FUZZY

Table 10: Z-Scores of criteria and its total

VENDOR	Z-Score of Price	Z-Score of Quality (in terms of Impact Factor)	Z-Score of Capacity	Z-Score of Time Delay	Total of Z-Scores
1	.08255	.5037	5.7726	5.3232	11.6821
2	.4432	8.1989	.09117	.0014	8.7346
3	.2857	.9568	3.3102	.0435	4.5961
4	4.334	.04067	3.0911	6.1511	13.617
5	1.8771	1.5292	1.4637	6.4315	11.302
6	2.6356	2.9429	4.0193	3.2698	12.867
7	4.4329	1.5595	3.7869	6.1722	15.952
8	.4464	.5314	2.0263	3.1646	6.169
9	.5246	3.810	1.0208	5.002	10.357
10	2.2201	.8301	7.4188	4.4404	14.909

Value of the objective function =15855.09

Allocation of order to the vendors is as follows:

X_1=0,X_2=0,X_3=0,X_4=,X_5=0,X_6=0,X_7=907,X_8=0,X_9=0,X_{10}=93

Comment: The maximum allocation goes to the ninth vendor i.e. 893 (same as crisp case). The value of objective function is expectedly more than the crisp case because of an increased range in membership of objective function value.

SAMPLE 3
CASE 1: CRISP

Table 11: Z-Scores of criteria and its total

VENDOR	Z-Score of Price	Z-Score of Quality (in terms of Impact Factor)	Z-Score of Capacity	Z-Score of Time Delay	Total of Z-Scores
1	.13759	1.8178	3.0621	.061512	5.0788
2	1.9655	.1461	2.6734	3.2308	8.0159
3	.0639	.02776	2.2293	2.4458	4.7670
4	2.5836	.091298	1.1189	1.3269	5.1209
5	.5078	.89724	1.0541	.4550	2.9142
6	2.5005	3.3503	1.8869	1.4904	9.2303
7	.5015	1.0506	3.0066	.8941	5.4527
8	2.1231	.1320	.08253	2.9272	5.2650
9	.1089	1.2425	1.5168	1.3739	6.2244
10	.5077	.2432	.3694	.7940	1.9148

Value of the objective function =8993.492

Allocation of order to the vendors is as follows:

X_1=0,X_2=195,X_3=0,X_4=93,X_5=0,X_6= 805,X_7=0,X_8=0,X_9=0,X_{10}=0

Comment: Here the highest allocation goes to the sixth vendor whose quality in terms of IF is .5556, which is not good enough. In terms of Z-Scores cost is second highest but Capacity and time delay are not high enough. Also quality as judged by IF is moderate, it is to be understood that the optimal allocation which we have done is a case of constraint optimization and as such vendor may get an optimal allocation for a specific sample.

CASE 2: FUZZY

Table 12: Z-Scores of criteria and its total

VENDOR	Z-Score of Price	Z-Score of Quality (in terms of Impact Factor)	Z-Score of Capacity	Z-Score of Time Delay	Total of Z-Scores
1	.365912	4.4747	6.9890	.05932	11.889
2	4.47643	.3366	6.0268	7.3710	18.2107
3	.084729	.03108	5.0409	5.4599	10.6167
4	6.02581	.1797	2.4497	3.1524	11.8076
5	1.0980	1.4262	2.2919	1.0076	5.8238
6	5.6339	4.8161	4.2400	3.5916	18.2817
7	1.1448	4.3887	6.8623	2.0943	14.490
8	4.9959	.57785	.02849	6.7860	12.388
9	.1297	1.9413	3.3836	2.9802	8.4348
10	1.0447	.5527	.6871	1.4976	3.7821

Value of the objective function =18267.86

Allocation of order to the vendors is as follows:

$\mathbf{X_1=0, X_2=195, X_3=0, X_4=0, X_5=0, X_6=805, X_7=0, X_8=0, X_9=0, X_{10}=0}$

Comment: Here maximum allocation goes to the sixth vendor (same as crisp case). Again the value of objective function is all time high.

Step 3: Once the Z-Score are calculated, we use these Z-Scores as coefficients of the objective function (i.e.R_i). Using equations (7) to (8) as LPP formulations we calculate the order quantities to be allocated to the vendors.

Step 4: In order to find the maximum order quantities TVP we formulate the LPP model using equations (7) and (8) of the final model. The above LPP has been solved using the software LINDO 6.1.The optimal solution for the above formulation are shown in **Tables (4-9)** for both fuzzy and crisp case.

RESULTS AND DISCUSSION

For sample one, we observe that the value of objective function is very high for fuzzy case (22198.59) compared to crisp case (9677.909)

$TVP_{fuzzy} >> TVP_{crisp}$

When we look at the Z-Scores the values are very high for fuzzy case compared to crisp case. The allocation of order is according to higher value of Z-Scores. In both cases higher allocation is to the ninth vendor and value is 893 (both cases). There is variation in value of Z-Scores for next highest Z-scores i.e. for fuzzy case the next highest Z-Score is for eight vendor and order allocated is 107 and for crisp case the next highest Z-Score is for sixth vendor and allocation is 107.So there is uniformity in value of allocation even though the vendors are different. Also the vendor with IF=1 i.e. worst vendor the value of Z-Scores is minimum for seventh vendor and allocation is zero for both cases.

For sample two again here value of objective function is highest for fuzzy case compared to crisp case. The value of Objective function (fuzzy case) is 15855.09

$TVP_{fuzzy} >> TVP_{crisp}$

In sample two we observe that the value of Z-Scores is highest for seventh vendor (for both fuzzy and crisp case). The highest allocation is 907 for both the cases. If we look at the impact factor it is tending towards zero implying that the quality is best. For the next highest Z-Scores is different for both the cases .In crisp case it is the fourth vendor getting an allocation of order 93.In fuzzy case it is the tenth vendor getting an allocation of order 93.For IF=1,the Z-Scores are not the lowest as compared to sample one. But the allocation of order is zero being worst in quality.

In sample three here the value of objective function is very high for fuzzy case i.e. 18267.86 compared to crisp case where it is 8993.492.

$TVP_{fuzzy} >> TVP_{crisp}$

The highest value of Z-Scores is for vendor six (both fuzzy and crisp case). The allocation of order is 805. The next highest Z-Score is for vendor two (both fuzzy and crisp case). The order allocation is 195 for both the cases. No worst vendor has been reported since we do not have IF=1.

Conclusions:

From above observations of the results from the three samples we observe that results for fuzzy cases are definitely better than crisp case probably due to randomness of data generated by simulation. The value of objective function being almost double for fuzzy case compared to crisp case. Also the vendor with highest Z-Scores was allocated the highest order first. The maximum allocation was for the highest Z-Scores.

In each sample whether for fuzzy or crisp the highest allocated vendor also had a moderate to good quality in terms of the impact factor. Since the samples were randomly selected, it means that the impact factor may be regarded as an indirect measure of quality. We feel the present results to be stronger as compared to those of [***Kaur and Chakraborty, (2007***)] where the highest allocation went to the vendor with the best IF in that the previous case was on a secondary data.

In case of large number of vendors, Andrew's plot [***Kaur and Chakraborty, (2007***)], can be effectively used for identifying clusters of vendors and keeping only one (say the one with best impact factor) for consideration and leaving the rest thus reducing the search space for final optimal allocation.

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APPENDIX

PROGRAM FOR GENERATING THE RANDOM NUMBERS IN QBASIC

Program 1

```
REM case 4 simulation
CLS
RANDOMIZE TIMER
s = 0
FOR trial = 1 TO 1000
min = RND
FOR j = 2 TO 10
x = RND
IF x < min THEN min = x
NEXT j
s = s + min
NEXT trial
PRINT "mean="; s / 1000
END
```

Program 2

```
REM generating 10 random integers between a and b
CLS
INPUT "enter a,b"; a, b
RANDOMIZE TIMER
FOR i = 1 TO 10
PRINT INT(RND * (b - a + 1)) + a
NEXT i
END
```

Program 3

```
REM generating 10 independent exponential variates with mean 1
CLS
RANDOMIZE TIMER
FOR i = 1 TO 10
PRINT (-1) * LOG(1 - RND)
NEXT i
END
```

These codes were run in QBASIC version 4.5 in our system (Pentium4)